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SPECTRAL SENSITIVITY OF HUMAN VISION TO THE LIGHT PULSES

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Abstract. *In the paper we represent experimental results of the research of human vision sensitivity to pulsed radiation of discrete light emitting diodes (LEDs) of different colors when their dissipated electrical power was the same. We used color components of RGB LED matrix and determined the values of the dissipated power at which resultant LED radiation was perceived as white light. These power values were used to investigate sensitivity of human eye to radiation of each color of RGB matrix. Spectral characteristic of RGB LED under investigation was checked for presence of additional spectral components. The results we obtained give the possibility to develop information systems with concealment of the data transfer process using white light which color components are informative.*

Keywords: RGB LED, light pulse, human vision, information system

CZUŁOŚĆ WIDMOWA WZROKU LUDZKIEGO NA IMPULSY ŚWIATŁA

Streszczenie. *W artykule zostały przedstawione wyniki badań eksperymentalnych czułości wzroku ludzkiego na promieniowanie impulsowe diod LED o różnych kolorach światła przy jednakowych rozpraszanych na nich mocach elektrycznych. Za pomocą macierzy RGB określa się wielkości mocy rozpraszanej na diodach LED macierzy, przy których wynikające promieniowanie diod LED jest odbierane jako białe. W tak określonych mocach elektrycznych została zbadana czułość ludzkiego widzenia na pulsacyjne promieniowanie każdej z diod LED matrycy RGB. Charakterystyka widmowa badanej diody RGB LED została sprawdzona pod kątem obecności dodatkowych składowych widmowych. Uzyskane wyniki umożliwią opracowanie systemów ukrytej transmisji informacji za pomocą światła białego, którego składowe widmowe mają charakter informacyjny*

Słowa kluczowe: dioda RGB LED, impuls świetlny, ludzki wzrok, system informacyjny

Introduction

Subjective human perception of light pulses is widely used in medicine for diagnostics of diseases of human vision. These methods are based, in particular, on the Talbot-Plateau law [1] and the Ferry-Porter law [2]. The reaction of human eye to sequences of light pulses is described by Talbot-Plateau law. According to this law when flashes (light pulses) effect on observer's eye with frequency higher then critical fusion frequency F_{limFFT} (flicker fusion threshold) its sensation becomes continuous. The effect of light pulses fusion causes a visual sensation identical to created by the light of constant brightness. The effective luminance L_{ef} will be the average luminance during a period:

$$L_{ef} = L \cdot t_1 / (t_1 + t_2), \tag{1}$$

where t_1 is duration of light pulses, t_2 is time interval between two adjacent pulses, L *is* luminance of light pulses.

Flicker fusion threshold F_{limFFT} can be calculated after the Ferry-Porter law:

$$F_{\lim FFT} = a \cdot \mathbf{lg} L_{ef} + b, \tag{2}$$

where L_{ef} is effective luminance, parameter $a = 12.5$ for cone (day) vision and $a = 1.5$ for rod (night) vision, $b = 37$.

Appearance of powerful LED light sources gives the opportunity to expand the application of these laws beyond the scope of diagnosing human illness. They can be applied to develop information systems with concealment of the data transfer process.

Previous research shown that at nonzero background lighting level there is fairly wide interval of frequencies of pulse sequence, when human eye does not see light pulses. The investigations were carried out in the cases of direct and peripheral fields of view. Such sequence of light pulses can not be detected by traditional methods of photo and video recording.

This is connected with the problem of spectral distribution of frequencies of invisibility for white light. To solve this problem two experiments different in their approach were carried out. The essence of the first one was to find the frequencies of invisibility of three separate LEDs (red, green, blue) when the power, supplied to them, was the same.

In the second experiment we used RGB LED matrix and controlled the power given to each colour LED component. The value of the power was chosen so that resultant (total) radiation of LEDs was perceived by human vision as white light. The electrical power value, determined in such way remain permanent. In the experiment only the character of the radiated by colour LED components was changed: from continuous light it was transformed into pulsed light with adjustable frequency and duration.

Information systems of visual light are being actively developed [3] and offered on the market. In developing of such systems, it should be taken into account that human brain extremely negatively responds to action of two and more light stimuli operating with different frequency rhythms (for example, computer monitor, lighting system, etc.) [4]. At the same time ensuring the concealment of the data transfer process is also an important aspect of functioning of light information systems [5, 6].

It should be noted that the main task in this experiment was not the determination of colour. The main task of this experiment was the determination of light impulse from LED.

1. Spectral components of RGB LEDs matrix under investigation

Preliminary we studied radiation spectra of light emitting diodes which are parts of LED matrix with diameter 5 mm. Spectrum of LED radiation light flux was analysed using the spectrophotometer SF-4. The spectrophotometer sent the signal to photoelectronic multiplier (PEM). PEM transformed poor light flux to electrical signal. PEM output signal was measured by the voltmeter M95 in which there is no possibility of the sensitivity change. So RGB LED current was set to such a value that for maximum of LED spectral characteristic the voltmeter readings did not exceed 0.9 of voltmeter scale range.

Using this algorithm, we determined electrical current for all LEDs:

$$I_{green} = 0.10 \text{ mA}; \; I_{red} = 0.13 \text{ mA}; \; I_{blue} = 0.04 \text{ mA}.$$

Low level of the current of blue LED shows its highest efficiency of conversion of electrical energy to the light. Red LED is characterized by the lowest efficiency of conversion.

Experimental results of spectral distribution of relative intensity of light flux from every RGB matrix LED are represented in Fig. 1. In this figure you can see that RGB LED radiation spectrum consists of wavelengths of red (RED curve in Fig. 1); green (GREEN curve) and blue (BLUE curve) colours and has similar width of radiation spectra. Radiation spectrum width was determined at 0.707 level of radiation maximum. For blue and red components of matrix it is equal 13 nm, and for green one the radiation spectrum width is 15.6 nm.

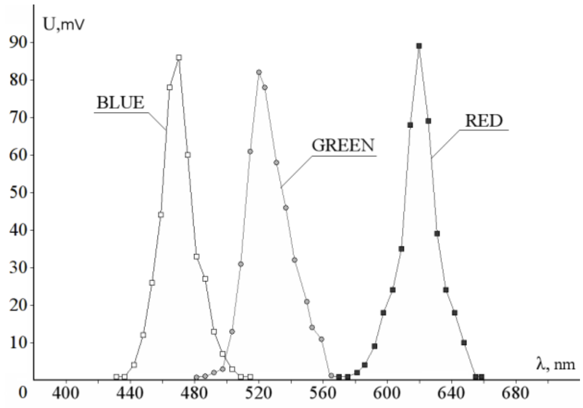

Fig. 1. Spectral distribution of relative intensity of light flux for different LEDs of RGB matrix

Experimental results could be changed under influence of any additional light source. Therefore, the experiments were conducted in dark room. There were no other light sources in this room. Background light also was formed using LED matrices Epistar 5730 (Fig. 2).

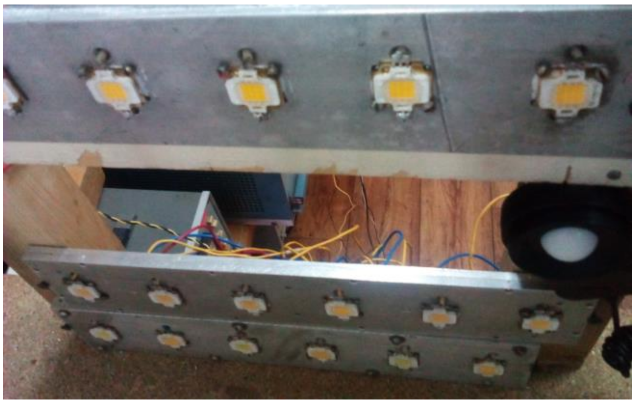

Fig. 2. Panels for forming background lighting

Radiation of these LED matrices is similar to white light spectrum. Background lighting level was controlled by changing the voltage on LED matrices. The distance between observer and LED (called as test-target) was 1 m. The experiment was conducted in the case of direct vision (4-7°) and constant duration of pulses (5 μs). Pulses of the same duration but different power were given to RGB LED leads. Mixing of colored LED radiation (switches S1, S2, S3 in Fig.3 were closed) formed the white light [7, 8]. Electrical pulses with the required parameters were formed using the pulsed generator G5-54. Output signal parameters of the generator were controlled by the digital oscilloscope TDS1012. Regulation of the current and consequently LED luminescence brightness was provided by the potentiometers R5, R6, R7 (Fig. 3). Resulting flux of radiated light was formed, as aforementioned, according to the criterion that the total emitted radiation is perceived as a white light. To meet this criterion the pulse power supplied to the LED must have the values represented in Table 1.

Table 1. The power of pulses supplied to RGB LED matrix components

Type of LED component	Power, W
Red	0.045
Green	0.017
Blue	0.016

Sizes of the LED under investigation are much more than for example sizes of monitor pixels of modern computers [9, 10, 11]. Therefore, mixing radiated LED light was less effective. To solve this problem the light radiated by LEDs was directed to a light-scattering screen.

Due to a significant own capacity of p-n junction (C_{pn}) of the LEDs we observed a post-emitting effect. To speed up the process of dissipating electrical power accumulated on p-n junction capacity we used the parallel load resistors R11, R12, R13 (Fig. 3) with resistance of 27 Ohm. Such value of resistance was chosen due to the condition that discharging time constant would be less than duration of electrical and consequently light pulses:

$$\tau_{dis.} << \tau_{pulse},$$

where $\tau_{dis.} = C_{pn}R_L$, R_L is load resistance.

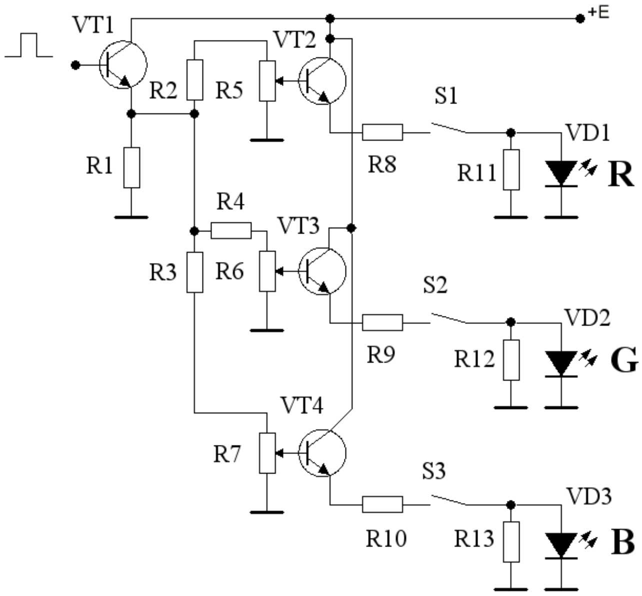

Fig. 3. Schematic circuit diagram of light pulses former

This allowed to obtain the form of the pulses radiated by LED as rectangular form of electrical pulses given to the LED.

During the experiment the RGB LED was studied to reveal the presence of “invisible” frequency ranges for every its spectral component. Electric energy brought to the LED was constant during the experiment. Its value allowed formation of white light after mixing of radiated colored light (switches S1, S2, S3 were closed). The results are represented in Fig. 4. White areas in all parts of small Fig. 4 correspond to the frequency range when human eye see the light radiation. Gray areas in all parts of small Fig. 4a correspond to the frequency range when human eye doesn't see the light radiation. It was found that the largest frequency range of "invisibility" among R, G, B LEDs under consideration is observed for a blue LED (Fig. 4c).

Light pulses threshold frequency above which light pulses are perceived by human vision as continuous radiation (white area in Fig. 4) significantly depends on background lighting level. For example, at E = 100 lx for green LED component this frequency is $F_{lim.green}$ = 3 kHz. In the case of the same background lighting level for red and blue LED components we obtained values $F_{lim.red}$ = 1.6 kHz and $F_{lim.blue}$ = 5.5 kHz, respectively. In the case of synthetic white light, formed by mixing color radiation of RGB LED all components, $F_{lim.white}$ = 7.1 kHz.

Threshold frequencies for background lighting level E = 160 lx are the following: $F_{lim.green}$ = 4.9 kHz, $F_{lim.red}$ = 2.7 kHz, $F_{lim.blue}$ = 7.7 kHz. At the same conditions for mixing (white) light the threshold frequency is $F_{lim.white}$ = 10 kHz.

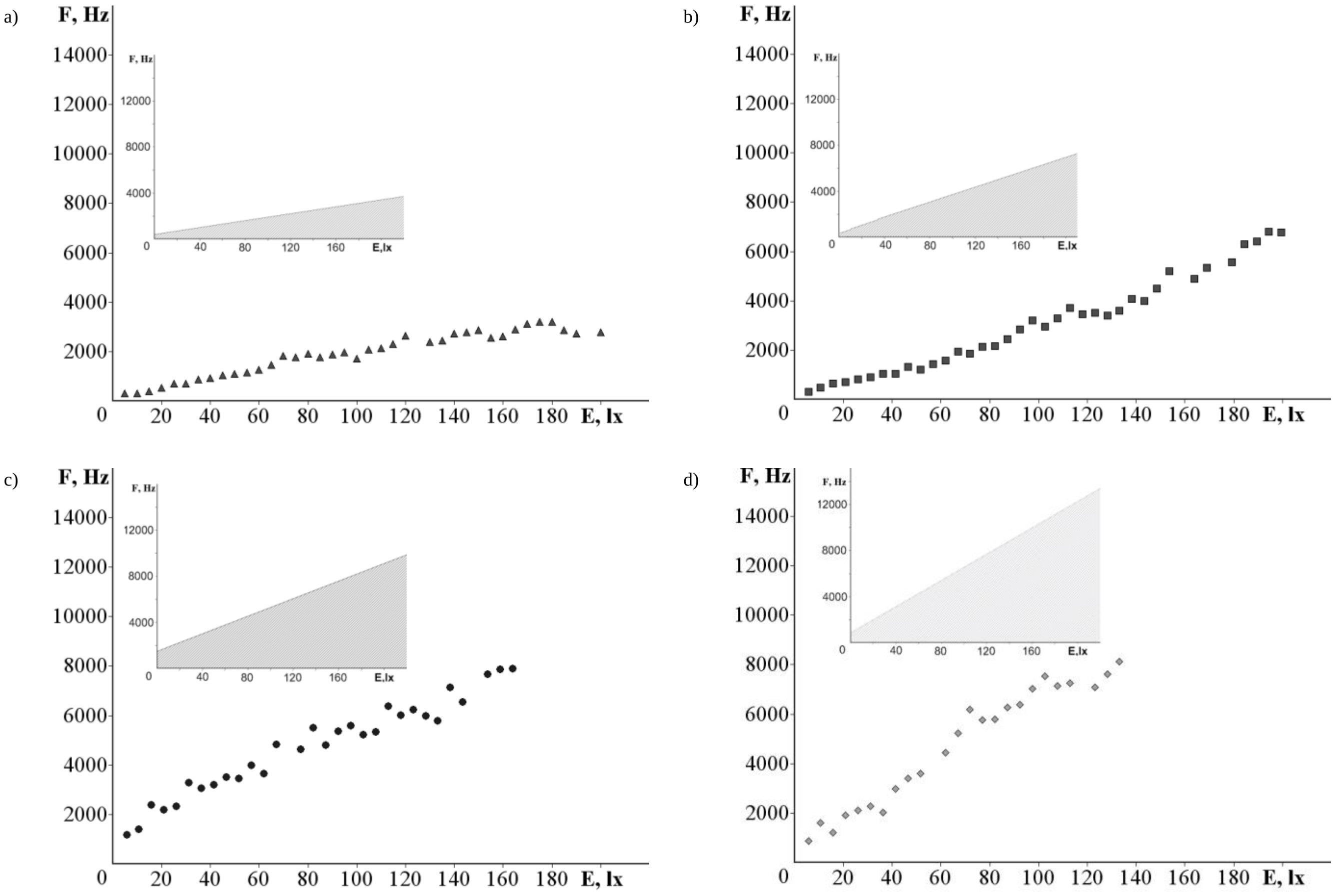

Fig. 4. Averaged experimental intensity of illumination – frequency dependencies of "invisible" radiation of green (a), red (b), blue (c) components of the RGB LED and their simultaneous radiation (white light) (d) (Approximation lines for experimental results, respectively. Gray areas correspond to "invisible" frequency range)

The rate of the change of the threshold frequency with the change of intensity of illumination varies for spectral components. Mark this parameter as $k = \Delta F/\Delta E$, where F is frequency (in Hz) at given level of background lighting (in lx). Table 2 presents k values for spectral components of artificially formed white light.

Table 2. The parameter k (at the level of background lighting E = 160 lx) for different spectral components of white light of the investigated LED

component	k, Hz / lx
Red	17
Green	30
Blue	48

2. Separate color LEDs study

Each separate LED was supplied by the power of 0.06 W, duration of the pulses in this experiment was 5 µs. In Fig. 5 intensity of illumination – frequency characteristics of "invisible" light pulses are represented.

It was determined that at background lighting level E = 100 lx average observer did not see light pulses from green LED when their frequency achieved the threshold 216 Hz. In the cases of red and blue LEDs threshold frequencies were 54 Hz and 72 Hz, respectively.

Consequently frequency threshold of 'invisibility' of green light LED is 4 times and 3 times greater than the threshold frequency of the red and blue LEDs, respectively.

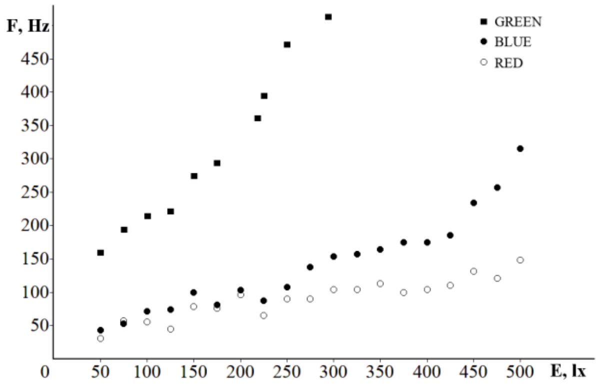

Fig. 5. Intensity of illumination -frequency dependence of radiation of green, red, blue LEDs

3. Summary

The lowest threshold frequencies were obtained for the green spectral component. This can be explained by the high sensitivity of human vision to green light.

The highest threshold frequencies were determined for the blue LED. Using the correlation between frequency of pulse sequence and bit rate one can say that for blue component this parameter is limited approximately to 7 kbit per second for background light level of 160 lx. Variable level of background lighting requires the development of smart control module for the information systems with concealment of data transfer.

The results of the research show that application of green and red spectral components of visible light in the information systems under consideration is ineffective.

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